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# 1976 NASA-ASEE Summer Faculty Systems Engineering Program

STANFORD UNIVERSITY - AMES RESEARCH LABORATORY

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This was the eleventh NASA-ASEE Summer Faculty Systems Engineering Program conducted by Stanford University and the Ames Research Laboratory. This year the topic, as originally stated to the Fellows, was "the design of a system to detect extra-solar planets." Appendix 1 contains the slightly expanded statement of this problem as it was included in the publicity for the workshop.

The participants were selected from some 150 applicants who indicated the Stanford Systems Engineering program as first choice. Selection was made by considering the following factors:

1. The probability of the applicant conducting systems engineering programs at his home school

2. Technical balance of the group

3. Age

4. Academic credentials

5. Interests

Appendix 2 lists the final participants and their institutions.

In general, the study followed the format which has been previously used in these workshops. The first phase was spent in becoming familiar with the many factors involved in the detection of extra-solar planets, gathering data in parametric form, and examining alternative concepts. As usual, expert lecturers were invited and did an excellent job. Four weeks were allocated to phase 1. The next phase of the study (three weeks) was spent in convergence and the final four weeks were spent in finalizing details.

The topic for this summer's study was suggested by the Director of Ames Research Center. It is of particular interest to the group at Ames studying the detection of extraterrestrial intelligence. Obviously, the existence of intelligent beings in space is a function of the number of inhabitable bodies. It therefore becomes extremely important to find whether planets are unique to the Sun or whether they are a common phenomena in the universe. Although it has been our policy to alternate study topics between space systems and systems with a higher social content, the topic was chosen for several reasons:

1. It was well sized. Preliminary work indicated that the system would possibly be earth-based, which would result in costs and resource expenditures of a magnitude which would be realistic to the summer group.

2. It was a high-technology system, and our experience has indicated that studies based on a high-technology system run more smoothly with a high degree of satisfaction on the part of the participants.

3. It was highly motivating and of great interest to the scientific community.

4. It was of high interest to Ames Research Center.

The topic proved to be an excellent one. The final system design is definitely a breakthrough and there is great interest at Ames in pursuing the project. The design process ran its usual course and the participants all had an excellent opportunity to experience the joys and the frustrations of an effort of this type. A couple of features of this particular study are perhaps worthy of specific mention.

1. The study contained "experts" among the participants. These people were involved in astronomy and were extremely fluent in many of the considerations necessary to define the system. Some resentment arose between the "experts" and the remaining participants. This has happened before in our studies. The resentment was discussed openly, understood by all, and did not seriously interfere with the study. However, it was real, and had the group not been such a compatible mix of personalities, could have been difficult to handle. The same problem existed in the Space Colony Study (Jerry O'Neill and his cohorts were "experts"), the Cyclops Study (Barney Oliver was an "expert") and to a lesser extent in the Artificial Carbohydrate Study (the enzyme chemists were "experts"). "Expert" participants is extremely valuable in achieving greater depth in a study as short as the summer workshops. However, we are also becoming increasingly aware of the resulting difficulty of the group dynamics.

2. As in many of our high-technology studies, the final design outran the generalist capabilities of the participants. The technical considerations were advanced and the participants were forced to take inputs in disciplines other than their own on some faith. This is typical of a system design. However, it is always somewhat tricky in these summer groups because the participants have no history of working together, and therefore do not know how to judge each other's competence and because the group is publication-conscious, they begin to worry about the technical quality of the final report as the study progresses. This group voiced these concerns heavily at one of their final meetings. Although these concerns have been felt by members of previous groups, this was perhaps the first time they have been transmitted formally to the co-directors. This was undoubtedly a function of the presence of the above-mentioned "experts" and the amount of jargon in the area. Once again, this uneasiness did not handicap the study, but is a factor that is important in the group, particularly as it influences the creativity of their output. A group which is not confident of its technical ability cannot be expected to take the risk necessary to come up with a breakthrough.

The support and cooperation at the Ames Research Center was, as usual, excellent. In particular, the enthusiastic support of Hans Mark, the Director, and John Billingham, Head of the Extra-Terrestrial Intelligence Project and previous co-director of several Stanford-Ames summer studies, was invaluable. The final report of this study will probably be published as a NASA document. Two short documents are attached. The first

(Appendix 3) is a press release which concerns the topic of planetary detection. The second (Appendix 4) is a short description of imaging interferometry, which was the technique chosen by the group.

APPENDIX 1

## PROGRAM DESCRIPTION

For the coming summer we are planning to design a system for the detection of planets outside of our solar system. The discovery of planetary systems around other stars is of great scientific and philosophical importance. The detection of even a single planet would be an important validation of certain cosmological and astronomical theories. The detection of more than one would be of correspondingly greater interest. Ames Research Laboratory is particularly interested because of their involvement in studies having to do with the detection of extraterrestrial intelligence and the probability of life. Such studies are heavily dependent on probability of planetary existence outside of the solar system.

Preliminary work has indicated that there are several feasible techiques for the discovery of other planets. These could be applied either from the earth's surface, from balloon-based instruments or from the earth's orbiting observatories. The summer study will first of all study the advantages and disadvantages of various strategies for the detection of planets. It will then proceed with a design leading to a specific system.

This topic should be an excellent one for a systems design study for a number of reasons. It is sufficiently complex and interdisciplinary that the systems design approach becomes valid. It has been studied sufficiently to adequately bound the design. It is, above all, technically challenging and intellectually broadening.

APPENDIX 2

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APPENDIX 3

# PROJECT ORION: A DESIGN STUDY OF SYSTEMS FOR DETECTING EXTRASOLAR PLANETS

Every summer for the past eight years, Ames Research Center and Stanford University have jointly coordinated NASA-ASEE design studies on a wide variety of topics. This summer, the study has considered the design of systems which would enable mankind to address a fundamental and as yet unanswered question; "Are planetary systems a common occurrence in the Galaxy, or is the solar system unique?"

The efforts of this summer were directed primarily toward the design of an ultimate telescope for the purpose of astrometric detection of planets. Astrometry is that branch of astronomy concerned with precise determinations of the position of stars. If a star has a planetary companion, the apparent motion of the star across the sky will undergo a small, but in principle, detectable wobble. Some feeling for the magnitude of the task can be had from the following example. Detection of the wobble in the Sun's motion due to Jupiter, as viewed from the nearest star, is equivalent to detecting a motion of only 1/20 of an inch at a distance of 40 miles, roughly the distance from Ames to the Golden Gate Bridge. The ability to detect motion on that scale is an order of magnitude beyond present telescopes The imaging interferometer astrometric telescope designed this summer is capable of measuring the equivalent of only 1 to 3 thousandths of an inch motion at a distance of 40 miles. This instrument would be able to detect Jovian mass planets around most of the stars within 150 light years of the Sun.

An instrument of this sensitivity is able to extend other horizons as well. The cosmological distance scale is established through a chain of distance markers. An important link in that chain, parallax measurements of distance, could be extended nearly two orders of magnitude. The ability to accurately measure the distance to any star within 30,000 light years of the Sun also means that the absolute or intrinsic brightness of all such stars would be precisely determined. Knowledge of the intrinsic brightness of so many stars would provide two important developments in astrophysics; establishment of a firm empirical foundation for the study of stellar structure, and provision of absolute calibration of other techniques presently used to estimate the intrinsic brightness of distant stars.

The motivation behind Project Orion can perhaps be best understood by answering the question, "Why is a search for other planetary systems important?" In large measure, the answer to that question is contained in two topics: the origin of the solar system and the existence of extraterrestrial intelligence, which seem at first glance unrelated to one another.

Speculation concerning the origin of the solar system is as old as man himself. The "Modern" era of such speculation is generally identified with the Copernican revolution, which showed that the Earth was not the center of the universe. The major cosmogonic hypotheses of this early period were those of LaPlace and Kant. Although differing from each other in detail, the hypotheses were similar in that they both envisioned the planets as having formed from material that was spun off of the Sun. These hypotheses were discarded a little over a century after they were advanced when it was realized that the Sun, which has about 99 percent of the mass in the solar system, has only about 2 percent of the angular momentum of the solar system. The principal reason these hypotheses fell into disfavor was that at the time of this observational discovery, there was no known mechansism which would remove angular momentum from the Sun. The next generation of cosmogonic hypotheses were directed specifically at the problem of the angular momentum distribution in the solar system. Again, there were variations among the hypotheses, but they all tended to rely on singular or catastrophic events, such as a supernova or a stellar collision, to account for the solar system. Most of chese "catastrophic" hypothesis, which were popular in the first few decades of this century, have subsequently been shown to be physically untenable, or at the very least, highly unlikely. Most current hypotheses concerning the origin of the solar system are in many ways similar to the early hypotheses of LaPlace and Kant, in that they envision the planets forming from a nebula of gas and dust which is thought to have surrounded the Sun early in its history. This return to a "nebular" hypothesis has come about primarily for two reasons. First, unlike our counterparts of the previous century, we now know of several reasonable physical mechanisms which could have removed angular momentum from the Sun. Combining observational studies of the rotational velocities of stars on the main sequence (stars of various masses which, like the Sun, are deriving their luminous energy mainly from conversion of hydrogen into helium) with theoretical models of stellar structure, a consistent picture emerges which indicates that the Sun has very little angular momentum because most of it was removed by the solar wind, a plasma which continuously flows off of the Sun's surface. The second reason for a return to "nebular" hypotheses is that the advent of high speed electronic computers permits us to perform numerical experiments or modelling of the collapse of an interstellar cloud under the influence of its own gravity. It is generally felt that stars form by virtue of such a collapse process. Although these numerical experiments are not definitive, they strongly suggest that when a star is born, it is likely to have a circumstellar nebula, and that conditions in such a nebula would be highly conducive to the formation of planetary bodies. An equivalent way of expressing present cosmogonic hypotheses is to say that planetary system formation seems to be a natural, if not inevitable, aspect of the star formation process. The important distinction between the "catastrophic" and "nebular" cosmogonic hypotheses is that if the former is correct, planetary systems are the exception rather than the rule, whereas if the latter is correct, planetary systems are the rule. A systematic study of the frequency of occurrence of planetary systems would thus provide a valuable observational check on present theories of star formation.

The possible existence of extraterrestrial intelligence (ETI), as with speculation concerning the origin of the solar system, has long piqued man's curiosity. This curiosity has been the basis for a number of science fiction efforts. A graphic demonstration of this fascination with ETI is Orson Welles' radio dramatization in 1939 of the work by H.G. Wells entitled, "War of the Worlds." Until relatively recently, the subject of ETI had been the plaything of science fiction, and had received no serious consideration in the realm of scientific inquiry. However, Morrison and Cocconi (1959) took the first major step in changing the attitude of the scientific community toward the question of ETI. Their paper pointed out that there is a natural signpost in the electromagnetic spectrum which would be known to any advanced civilization, and that such civilizations might send radio signals at or near the frequency of this natural marker. This signpost is the 21 cm wavelength radiation arising from a hyperline transition in atomic hydrogen, the most abundant element in the universe. Shortly after the paper by Morrison and Cocconi, Frank Drake conducted a search, known as Project Ozma, for such signals. Drake's search was unsuccessful, but its importance cannot be overlooked, as it was the first serious attempt at detecting ETI signals. The relevance of a SETI (Search for ETI) effort to a search for other planetary systems lies in the fact that the only known intelligent life-form, namely ourselves, developed and was nurtured on a planet. If planets are required for the existence of ETI, knowledge of the frequency of occurrence of planetary systems is clearly highly desirable.

A systematic search for other planetary systems would thus reveal whether there is justification in arguing that a natural, perhaps even causal, relation exists between the phenomenon of star formation, which has occurred some $10^{11}$ times in the Galaxy, and the existence of ETI. The detection of other planetary systems is difficult; present observational techniques and instrumentation are at best marginal in terms of their ability to carry out such a search. The purpose of this Design Study was to apply modern technology to the problem in the form of specific design concepts for systems which could successfully mount a search for other planetary systems. The Earth is an object of exquisite beauty, and to the extent that this study is instrumental in the discovery of another such object, it will have served mankind an invaluable service.

# APPENDIX 4

## PRINCIPLE OF OPERATION OF IMAGING INTERFEROMETER

If the Earth had no atmosphere, every star seen through a telescope would look like a small, bright, steady disk. However, we have an atmosphere which is in turbulent motion. Therefore, when we look at stars through a small telescope, each star rapidly oscillates. Precise position of a particular star relative to other stars is difficult to measure because of this motion, especially since oscillations of various stars caused by the Earth's atmosphere are independent of each other.

The situation is improved if we use two telescopes to form together one image of a star field. This is a radically new idea on which our imaging interferometer is based. The interferometer consists of two telescopes, each having one movable flat mirror and two stationary concave mirrors, enclosed in a vacuum (Fig. 1).

Stellar images from the two telescopes either add together in phase or interfere and cancel each other. Therefore, an image of a star, formed by two telescopes together, is a round disk crossed by many dark and bright, rainbow colored, parallel fringes. The central bright fringe is white. This white fringe defines the precise position of a star in the horizontal direction with little effect from the Earth's atmosphere.

The white fringe is seen at the point where the lengths of the two light paths from a star through the two telescopes are equal, to within 1/10 of the wavelength of light (about 1/50,000 of an inch).

Let us suppose that we look at a star similar to our Sun but 10 light years away. Let this star have a massive planet, like Jupiter. As the planet moves around the star, the star wobbles around the center of mass of the planetary system. The size of this wobble amounts to one billionth of the distance from the star to us.

How does one detect a shift of a star in the sky amounting to one billionth of its distance? With the instrument which we designed it is simple: separation between the flat mirrors of the two telescopes must be a billion times larger than the accuracy with which we measure the position of the white fringe formed by combining the stellar light with the two telescopes. We measure the position of the white fringe to within $\lambda/10$, so the separation between the telescopes must be equal to 100 million lengths. This amounts to 60 yards, the separation which we adopted. By increasing the separation between the telescopes we increase the precision of measurements.

One interferometer consisting of two telescopes measures only a horizontal component of separation between the two stars. We observe a star field when it is in the southeast, then we wait a few hours until it moves to the southwestern part of the sky and repeat the measurement with another interferometer pointing southwest. This horizontal component of separation between the two stars is almost perpendicular to the component measured in southeast (Figure 2). Therefore, we need two interferometers (Figure 3) to measure two perpendicular components of separation between the two stars.

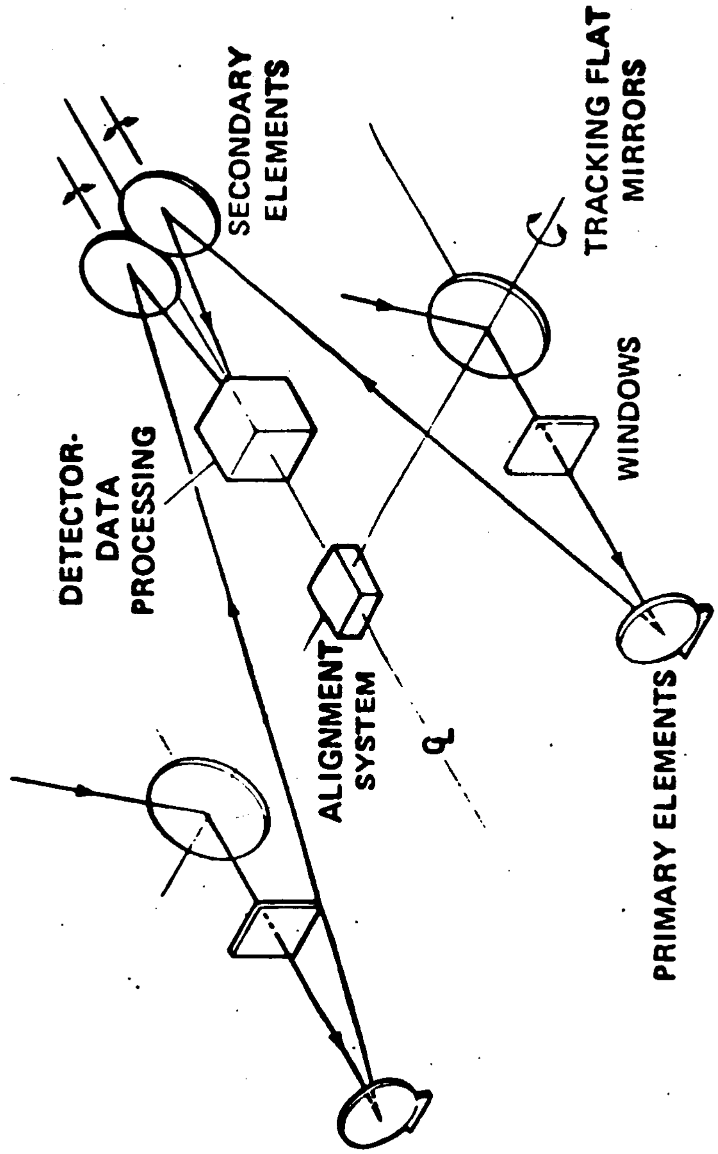
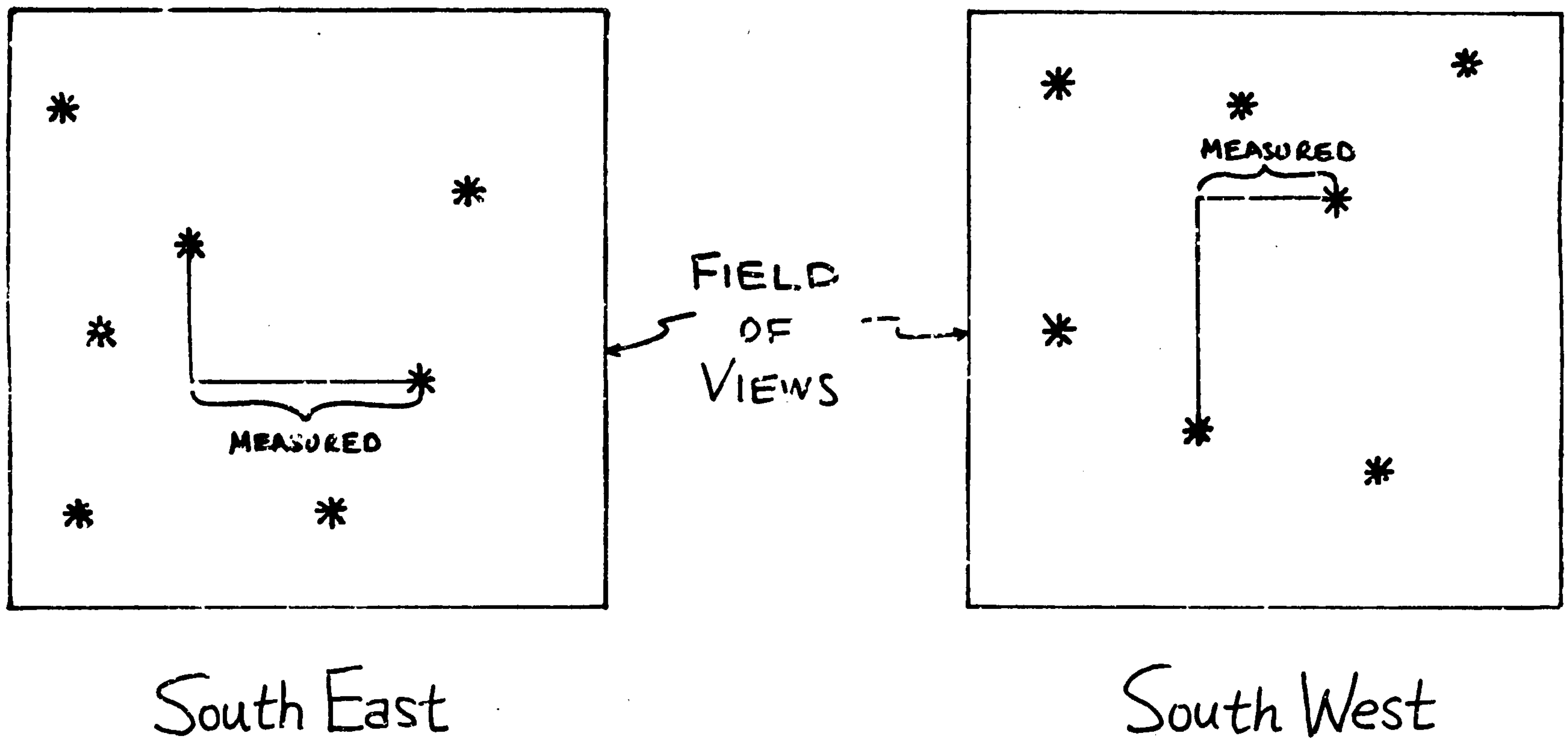

DETECTOR-
DATA
PROCESSING
SECONDARY
ELEMENTS
TRACKING FLAT
MIRRORS
WINDOWS
ALIGNMENT
SYSTEM
PRIMARY ELEMENTS

FIGURE 1




THE NEED FOR TWO INTERFEROMETERS

FIGURE 2

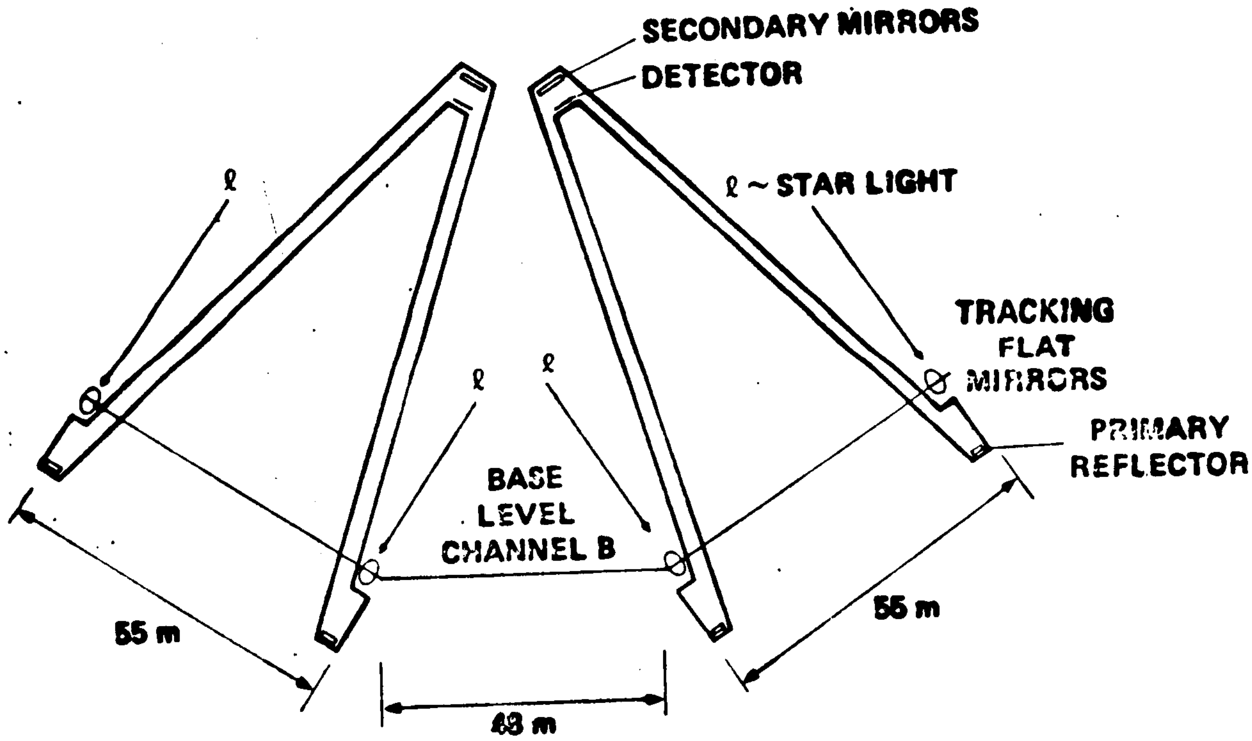



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FIGURE 3